6/21/06
TD-06-050

HFDA07 Test Summary

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Content:

1. Introduction

HFDA07 was delivered on April 11th, 2006. The magnet was installed into the VMTF dewar and it was electrically checked by the end of April 17th, 2006. The VMTF dewar was filled with liquid helium on April 19th 2006. First thermal cycle of the magnet has been completed on May 5th, 2006. There were no modifications introduced for the second test cycle. The second thermal cycle was started on June 14th , 2006 and it was finished on June 20st,2006. The magnet still remained in cold condition for PS tests. Finally the magnet has been removed from the VMTF dewar on June 26th, 2006.

2. Quench History

The magnet test program has started with quench training at 20 A/s ramp rate. The first quench was at high current of 16703 A. This quench current was consistent with the expectations that the newly assembled magnet had coils from both HFDA05 and HFDA06 magnets. This magnet exhibited practically no training.

After the third quench during noise studies a 10000A manual trip was initiated. AQD ground current detection system observed the trip and reacted the way it supposes to react. It overwrote the dump fire and initiated a slow ramp down event. Since meantime a heater fired and quenched the coil relatively high current was flowing in the resistive coils. The coils heated up and consequently the power supply voltage hit its 30V limit and the current started to drop. This event lasted 3-4 second. The accumulated quench integral value was over 40 MIITs. All of the LHe was evaporated from the VMTF dewar and magnet practically warmed up over room temperature.

After this forced Thermal Cycle we cooled down the magnet again to 4.45K and the first quench was the same as current level as the previous quench taken before the forced TC. We concluded that there were no any quench performance changes observed.

The program continued with ramp rate dependence studies at 4.5K, then we cooled it down to 2.2K and quenched few times. The magnet training was also short and it reached its critical current limit. This was confirmed by performing ramp rate and temperature dependence studies.

The quench history plot is presented in Figure 2-1. and in Table 2-1.

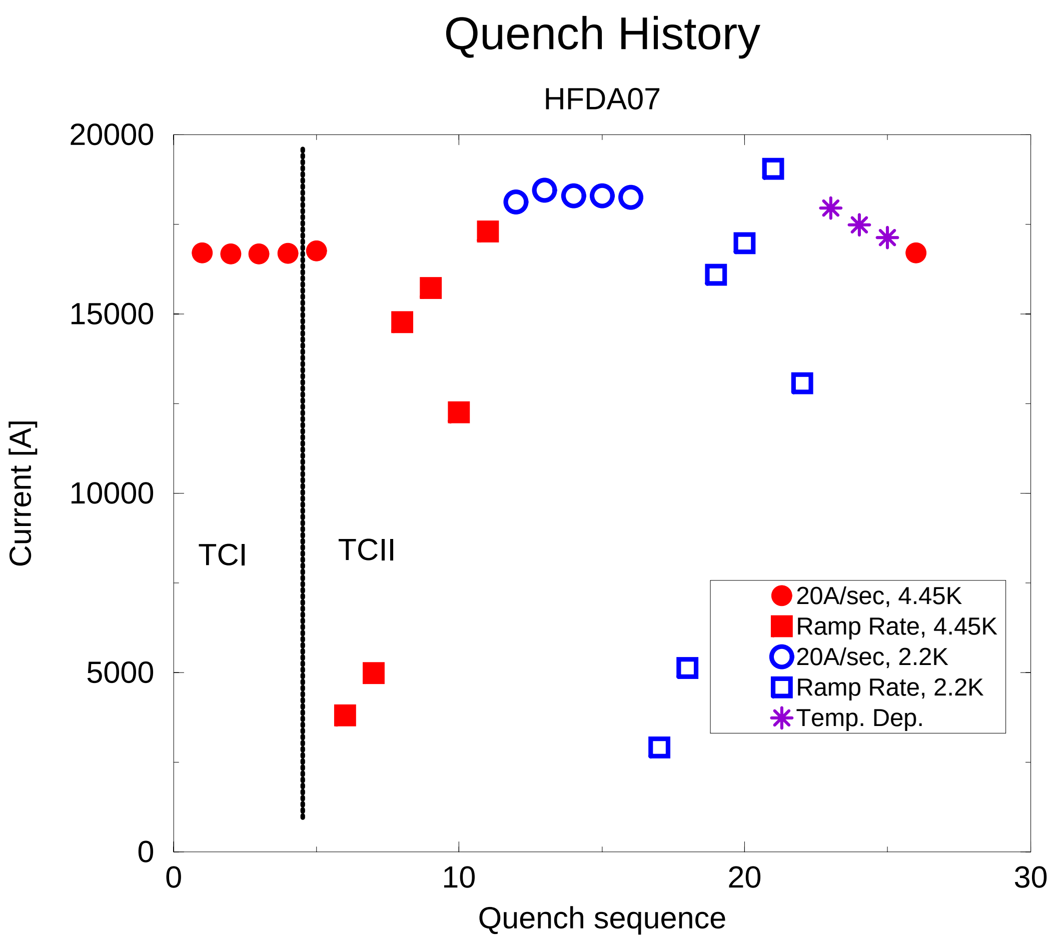

Figure 2-1. Quench history

Table 2-I. Quench summary table

File	Current [A]	dIdt	t_{quench}	MIITs	QDC	1^{st} VTseg	Mag Temp Bot Left	Comment
hfda07.Quench.060419151259.355	0	0					4.418	Trip for no reason since we had no current in the magnet..
hfda07.Quench.060419152142.737	0	20					4.416	trip during ramp up
hfda07.Quench.060419154259.832	0	20					4.416	trip again we saved the data to check what initiated the trip
hfda07.Quench.060419154944.710	0	20					4.413	trip again
hfda07.Quench.060419161126.869	1000	0					4.414	1000A manual trip
hfda07.Quench.060419162808.862	0	0					4.413	TRIP TO CHECK QA SIGNALS
hfda07.Quench.060419165918.812	5000	0	-0.4756	10.68	HcoilHcoil		4.410	5000A HEATER INDUCED QUENCH
hfda07.Quench.060419173036.013	**16703**	20	-0.0021	10.15	HcoilHcoil	Q19i14_Q14i14	4.424	1st quench, 20a/sec, Iq=16703.4A, 4.5K
hfda07.Quench.060419180925.773	**16672**	20	-0.0043	11.49	HcoilHcoil	Q19i14_Q14i14	4.439	2nd quench, 4.5K, 20A/s, Iq=16672.4A
hfda07.Quench.060419183428.138	**16677**	20	-0.0011	10.67	HcoilHcoil	QMS6_Q1i15	4.432	3rd quench, 4.5K, 20a/s, Iq=16677.4A
hfda07.Quench.060420131209.085	5000	0					4.413	ramp up 20A/sec 4.5K 1 power supply
hfda07.Quench.060420132305.582	10000	0					4.415	
hfda07.Quench.060420134313.865	0	0					4.415	
hfda07.Quench.060420140150.933	10000	0		35.35			4.415	
hfda07.Quench.060421143017.171	1000	0					4.426	1000A manual trip
hfda07.Quench.060421152211.721	1000	0					4.437	manual trip at 1000A, two PEIs, with capacitors in
hfda07.Quench.060421154802.999	1000	0					4.443	1000A manual trip, one PEI on, capacitor out
hfda07.Quench.060425103758.974	1000	0					4.430	1000A manual trip
hfda07.Quench.060425104858.332	1000	0					4.445	1000A manual trip using DQD leads
hfda07.Quench.060425114123.966	1000	0					4.421	1000A manual trip with DQD Coil and no delay of the dump, no heater protection applied
hfda07.Quench.060425115417.786	10000	0					4.423	10000A manual trip
hfda07.Quench.060425121522.448	**16693**	20	-0.0017	10.20	HcoilHcoil	Q14i12_Q19i12	4.434	4th quench, 20a/s, 4.5K, Iq=16693.8A

hfda07.Quench.060425165709.193	10000	0					4.461	AQD_LEads trip
hfda07.Quench.060425172443.601	10000	0					4.453	Trip at 10 kA, AQD LEADS
hfda07.Quench.060426113720.568	100	0					4.436	Manual trip @100A to determine the magnetude of the ground current dring phase back initiation
hfda07.Quench.060426115249.696	1000	0					4.432	Manual trip of dqd coil to test that the ground fault slow ramp dpwn does not over ride the PS phase back and dump fire. Note that the GF AQD threshold was decreased by a factor of 3.
hfda07.Quench.060426120128.687	1000	0					4.432	the last test since the GF did not trip last time. Manual trip with dqd coil to verify that teh GF does not over ride the ps phase back and dump fire..
hfda07.Quench.060426121215.063	1000	0					4.432	Did the sane test as before except we tripped on DQDleads. Verify that gndfalut didn't didn't override dump fire and phaseback
hfda07.Quench.060426134439.996	1000	0					4.430	Installed new QLM spare #2 performed a maunual DQD coil trip with a dump delay of 25 ms to make sure the gndfault does not override the df and PB
hfda07.Quench.060426141813.191	1000	0					4.426	Went to ste #2 with 2nd spare QLM performed a DQDleads trip to check that the dump delay is bypassed
hfda07.Quench.060426142754.326	1000	0					4.428	False trip
hfda07.Quench.060426143843.045	1000	0					4.430	Performed a gndfault trip and imediately (less than a sec.) did a manual whole coil trip
hfda07.Quench.060426145032.915	1000	0					4.427	Applied a gndfault trip and then a leadtrip to check that leadtrip dows not override gndfault
hfda07.Quench.060426150131.884	1000	0					4.427	False trip
hfda07.Quench.060426150746.289	0	0					4.429	Did HFU shut off and then a Whole coil trip
hfda07.Quench.060426152932.226	450	0					4.427	Shut off HFU and tripped aqdleads.
hfda07.Quench.060614154826.394	0	0						
hfda07.Quench.060616114716.013	2000	0					4.422	
hfda07.Quench.060616122336.161	**16764**	20	-0.0021	10.79	HcoilHcoil	Q19i14_Q14i14	4.437	1st quench, 20A/s, 4.43K, Iq= 16764.2A
hfda07.Quench.060616140715.190	**3798**	300	-0.0494	1.38	HcoilHcoil	Q1i15_Q14i12	4.416	2nd quench, 300A/sec, 4.42K, Iq=3798.4A
hfda07.Quench.060616142811.377	**4983**	200	-0.0263	1.77	HcoilHcoil	Q19i12_QNS2	4.418	3rd quench, 200A/sec, 4.42K, Iq=4982.8A

hfda07.Quench.060616150619.632	**14773**	100	-0.0024	9.05	HcoilHcoil	Q14i12_Q19i12	4.419	2th quench, 100A/sec, 4.42K, Iq=14773.2A
hfda07.Quench.060616153912.494	**15720**	50	-0.0022	9.97	HcoilHcoil	Q14i14_Q1i14	4.421	5th quench `, 50A/sec, 4.419K, Iq=15719.6A
hfda07.Quench.060616161351.772	**12266**	150	-0.0071	7.24	HcoilHcoil	Q1i15_Q14i12	4.422	5th quench, 150A/sec, 4.419K, Iq= 12265.8A
hfda07.Quench.060616165523.132	**17305**	1	-0.0113	14.08	HcoilHcoil	Q19i12_QNS2	4.452	6th quench, 1A/sec, 4.45K, Iq=17304.6A
hfda07.Quench.060619115225.526	**18128**	20	-0.0015	12.30	HcoilHcoil	Q10i14_Q14i14	2.156	Ramp to quench at 20 A/s, at 2.2K
hfda07.Quench.060619140824.585	**18447**	20	-0.0013	12.41	HcoilHcoil	Q19i12_QNS2	2.149	8th quench, 20A/sec, 2.2K, Iq=18447.2A
hfda07.Quench.060619143359.496	**18292**	20	-0.0015	12.20	HcoilHcoil	Q19i14_Q14i14	2.150	9th quench, 20A/sec, 2.2K, Iq=18292.2A
hfda07.Quench.060619145556.176	**18303**	20	-0.0025	12.71	HcoilHcoil	Q19i14_Q1i14	2.149	10th quench, 20A/sec, 2.2K, Iq=18302.6A
hfda07.Quench.060619151836.749	**18261**	20	-0.0013	12.32	HcoilHcoil	19i14_14i14	2.152	11th quench, 20A/sec, 2.2K, Iq=18260.8A
hfda07.Quench.060619152603.665	**2912**	300	-0.0652	0.96	HcoilHcoil	Q19i14_Q14i14	2.157	12th quench, 300A/sec, 2.2K, Iq=2912.4A
hfda07.Quench.060619154602.874	**5120**	200	-0.0273	1.89	HcoilHcoil	Q14i12_Q19i12	2.152	13th quench, 200A/s, 2.2K, Iq=5120.4A
hfda07.Quench.060619160017.275	**16101**	100	-0.0014	10.22	HcoilHcoil	Q14i14_Q1i14	2.153	14th quench, 100A/sec, 2.2K, Iq=16100.8A
hfda07.Quench.060619162345.391	**16975**	50	-0.0021	11.33	HcoilHcoil	Q14i14_Q1i14	2.153	15th quench, 50A/sec, 2.2K, Iq=16975.4A
hfda07.Quench.060619171008.378	**19047**	1	-0.0055		WcoilGnd	Q19i14_Q14i14	2.152	16th quench, 1A/sec, 2.2K, Iq=19046.6A
hfda07.Quench.060619173620.989	**13030**	150	-0.2124		HcoilHcoil	Q14i14_Q1i14	2.153	17th quench, 150A/sec, 2.2K, Tq~13030A
hfda07.Quench.060619182350.279	**17956**	20	-0.0015	12.19	HcoilHcoil	Q19i14_Q14i14	2.455	19th quench, 20A/sec, 2.453K, Iq=17958,8
hfda07.Quench.060619191155.329	**17489**	20	-0.0020	11.99	HcoilHcoil	Q19i14_Q14i14	3.257	19th quench, 20A/sec, 3.24K, Iq=17488.6
hfda07.Quench.060619195310.665	**17110**	20	-0.0014	11.28	HcoilHcoil	Q14i14_Q1i14	3.761	20th quench, 3.76K, 20A/sec, Iq~17110A
hfda07.Quench.060619211452.914	13690	20			SlWcoil		4.438	Lead trip
hfda07.Quench.060620075621.247	**16706**	20	-0.0017	10.81	HcoilHcoil	Q14i14_Q1i14	4.445	21st quench, 20A/sec, 4.45K, Iq=16705.6A

3. Ramp Rate Dependence

Ramp rate dependence studies are summarized in Figure 3-1. Quench current decreases with increasing ramp rate following a continuous function. This behavior is another confirmation that the magnets are at critical current limits. At ramp rates higher than 150 A/s the quench current drops dramatically and practically does not change with the current ramp rate. This behavior indicates that the magnet is limited by high losses and insufficient coil cooling conditions.

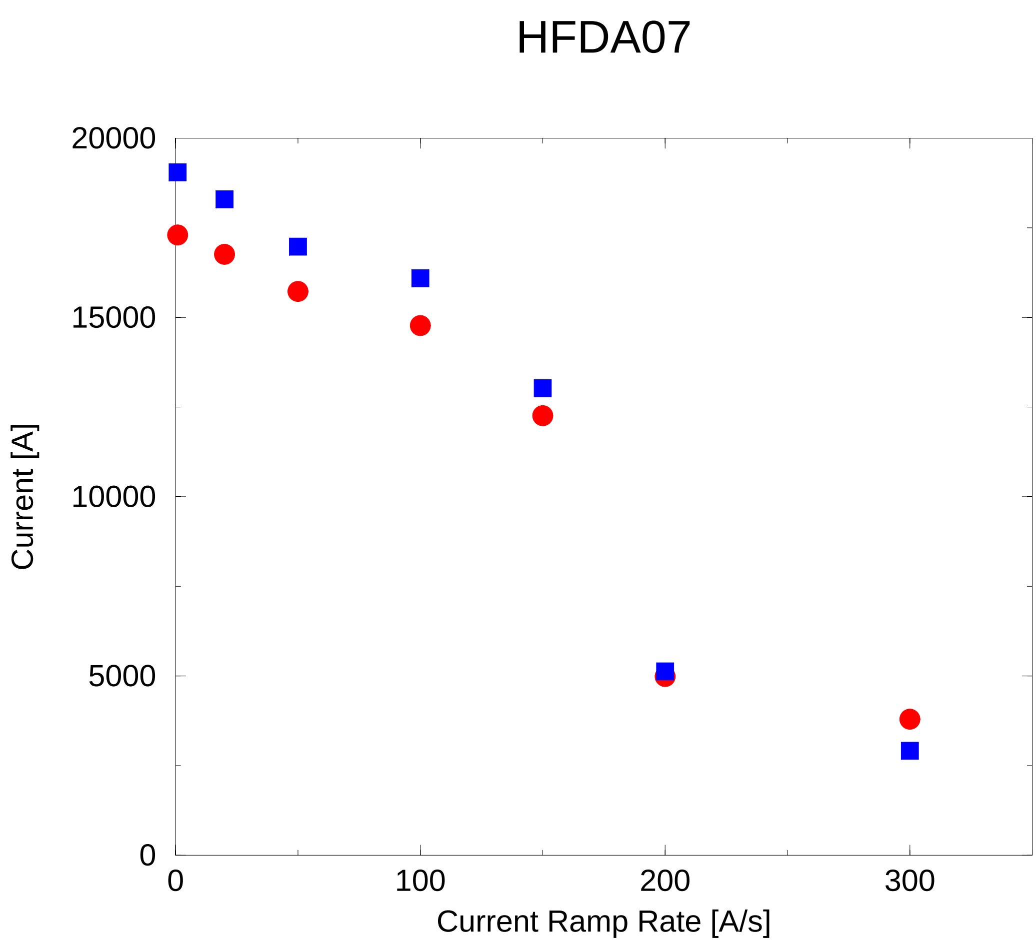

Figure 3-1. Current ramp rate dependence.

4. Temperature Dependence

Perfect temperature dependence was observed for HFDA07. The dependence of magnet quench current vs. temperature for HFDA07 is presented in Fig. 4-1. This dependence was measured during the second thermal cycle after the completion of magnet training at 4.5 K and 2.2 K. The data confirms that the magnet reached its short sample limit at all temperatures from 2.2 K to 4.5 K.

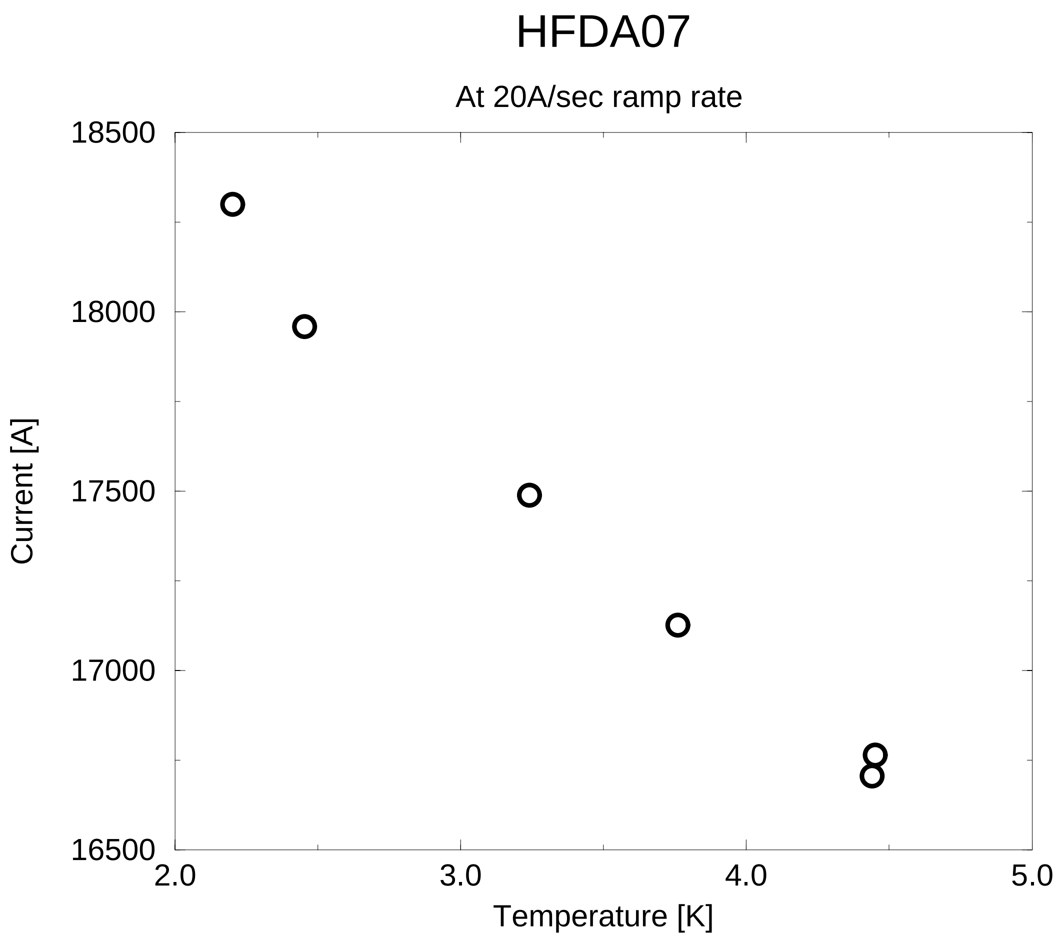

Figure 4-1. Temperature dependence studies.

5. Splice measurement

We performed splice measurements. The current was increased up to 15000 A and the voltage drops across the splices were recorded. Figure 5-1. shows the measurement results.

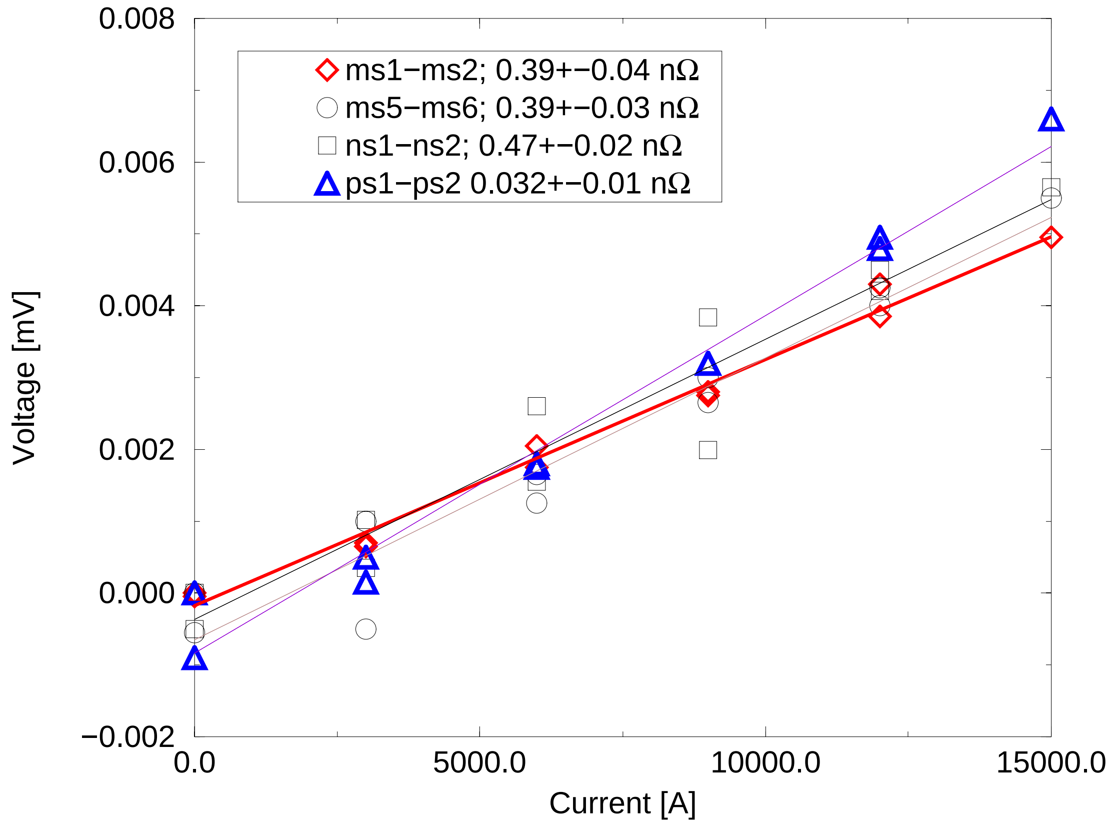

Figure 5-1. Splice measurement results

6. Magnetic measurements

Measurements of magnetic fields in the aperture were performed after cooling down in two thermal cycles. The measurement system was set up above VMTF cryostat and utilized 250 mm long probe (active length), 25 mm in diameter. The probe had a tangential winding for high order harmonics as well as dedicated dipole and quadrupole windings for low order harmonics and bucking. Probe coil voltages were sampled 128 times per rotation using HP3458 DVMs and read on the subsequent rotation. The probe rotation period was ~3s. An additional DVM was used to monitor the magnet current. DVMs were triggered simultaneously by an angular encoder on the probe shaft, synchronizing measurements of the field and current. A probe centering correction was performed by zeroing the unallowed by the dipole symmetry a_8/a_{10} and b_8/b_{10}. At constant current, centering was performed for each rotation. In current cycles it was done using the data taken between 2 kA and 3 kA on both up and down ramps in the first cycle. The main field was assumed to be pure normal (no skew dipole component) and a corresponding field angle was assigned. The field in the magnet body was represented in terms of harmonic coefficients defined by the expansion:

$$B_y + iB_x = B_1 \times 10^{-4} \sum_{n=1}^{\infty} (b_n + ia_n) \left(\frac{x + iy}{r_0} \right)^{n-1} ,$$

where B_x and B_y are horizontal and vertical transverse field components, B_1 is the dipole field component, and b_n and a_n are the $2n$-pole coefficients at a reference radius r_0.

A right-hand Cartesian coordinate system was defined with Z-axis at the center of the magnet aperture, pointing from return to lead end and the Y-axis coinciding with the dipole field vector. In this note the field harmonics are reported at r_0=10 mm and Z=0 mm (magnet center).

Z-scans

The Z-scan was performed at -0.50, -0.25, 0, 0.25, 0.50, 0.75, 1.00 m coordinates at 4000 A and 10000 A at ramps up and down following the pre-cycle up to 12000 A. Figures 1-2 present the main field components and transfer functions and Figures 3-10 show low-order harmonics, normalized by the main field component at Z=0, averaged between up and down ramps for the "cold" measurements.

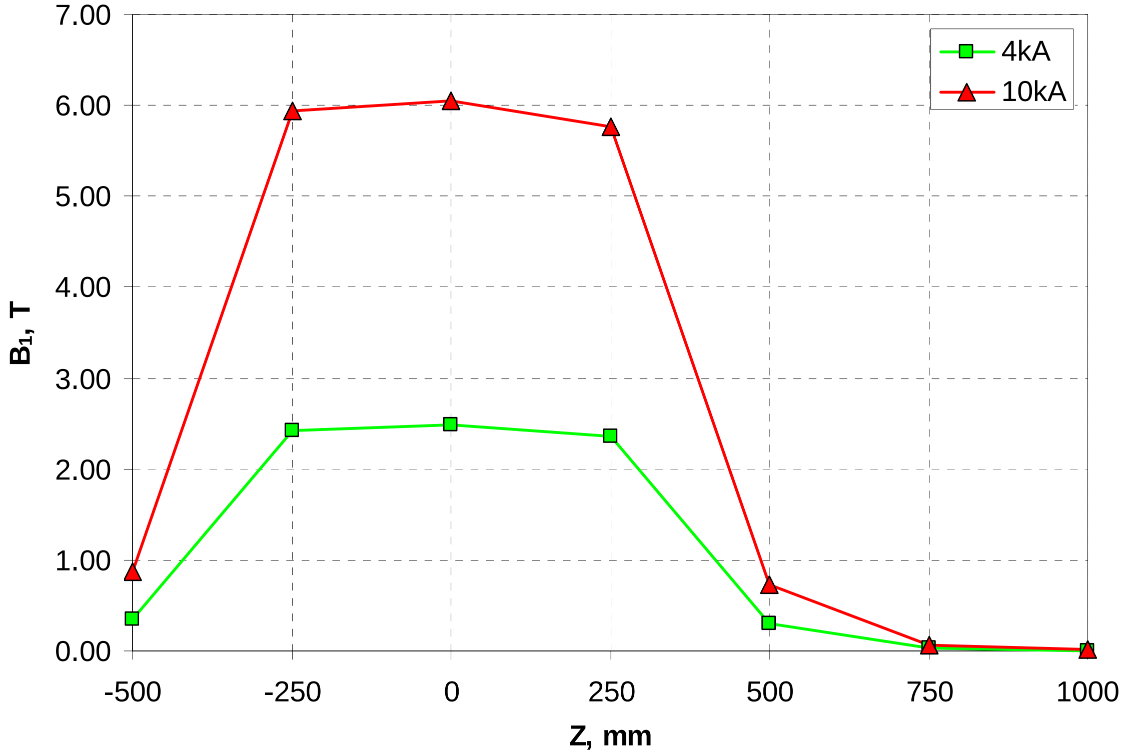

Figure 1. Main field component along Z-axis.

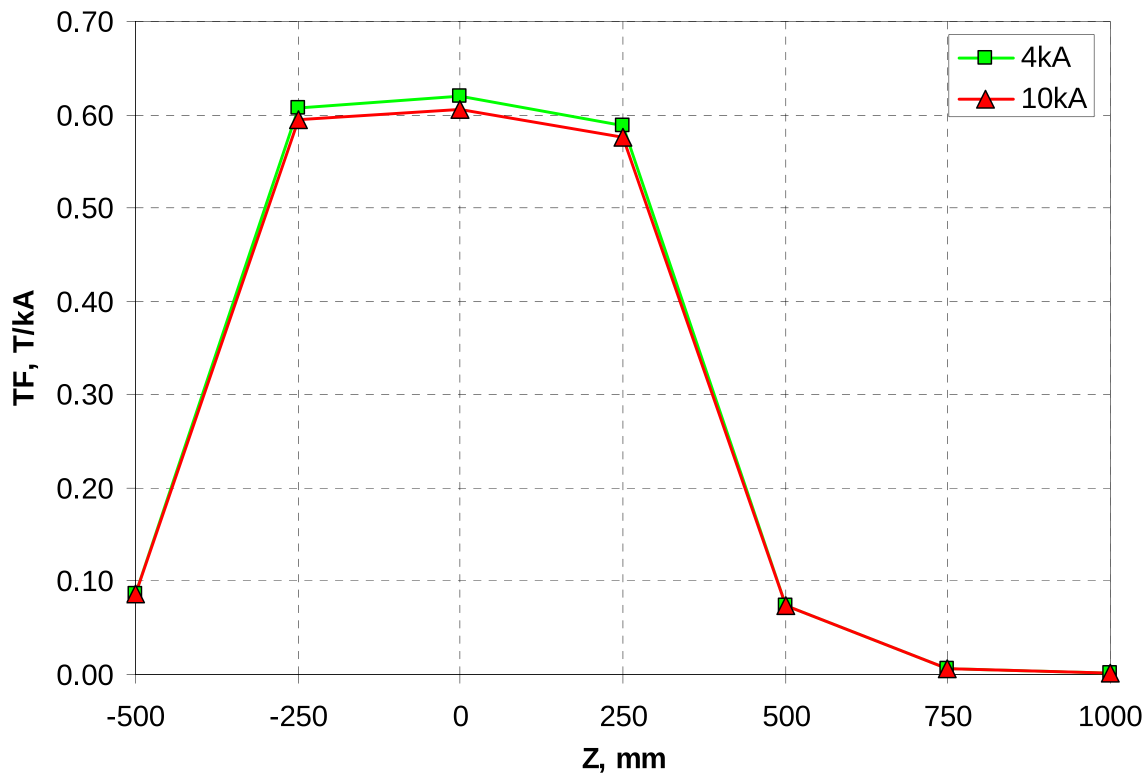

Figure 2. Transfer function along Z-axis.

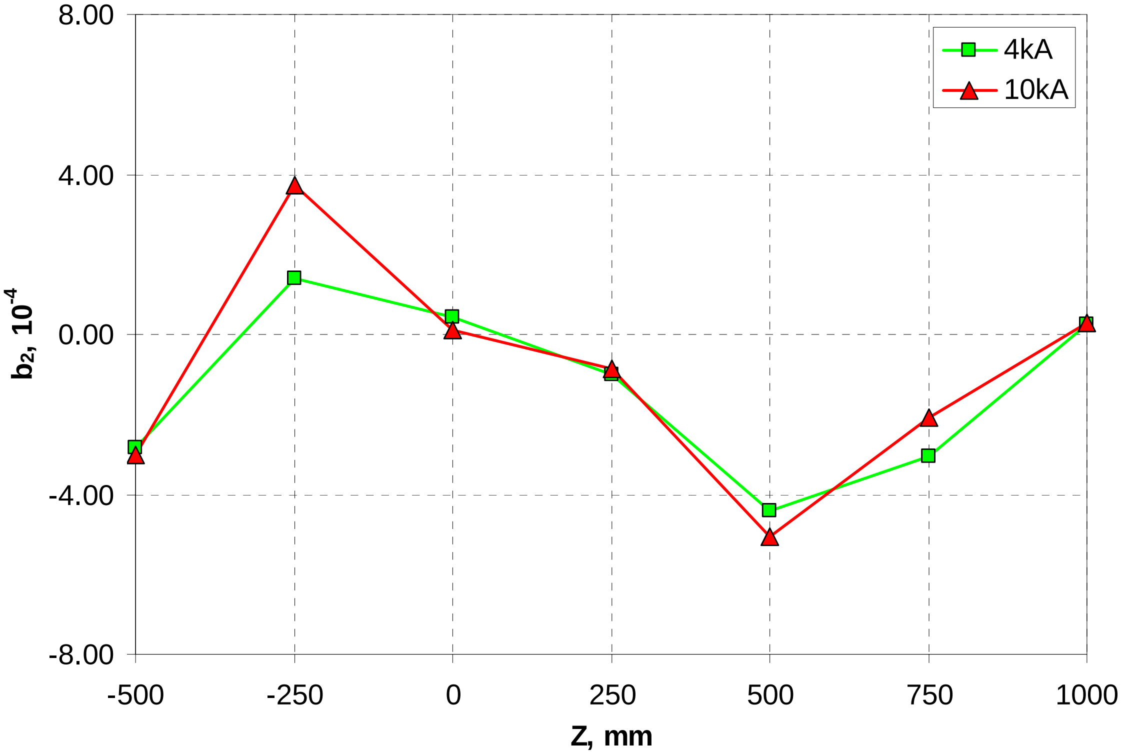

Figure 3. Normal quadrupole along Z-axis.

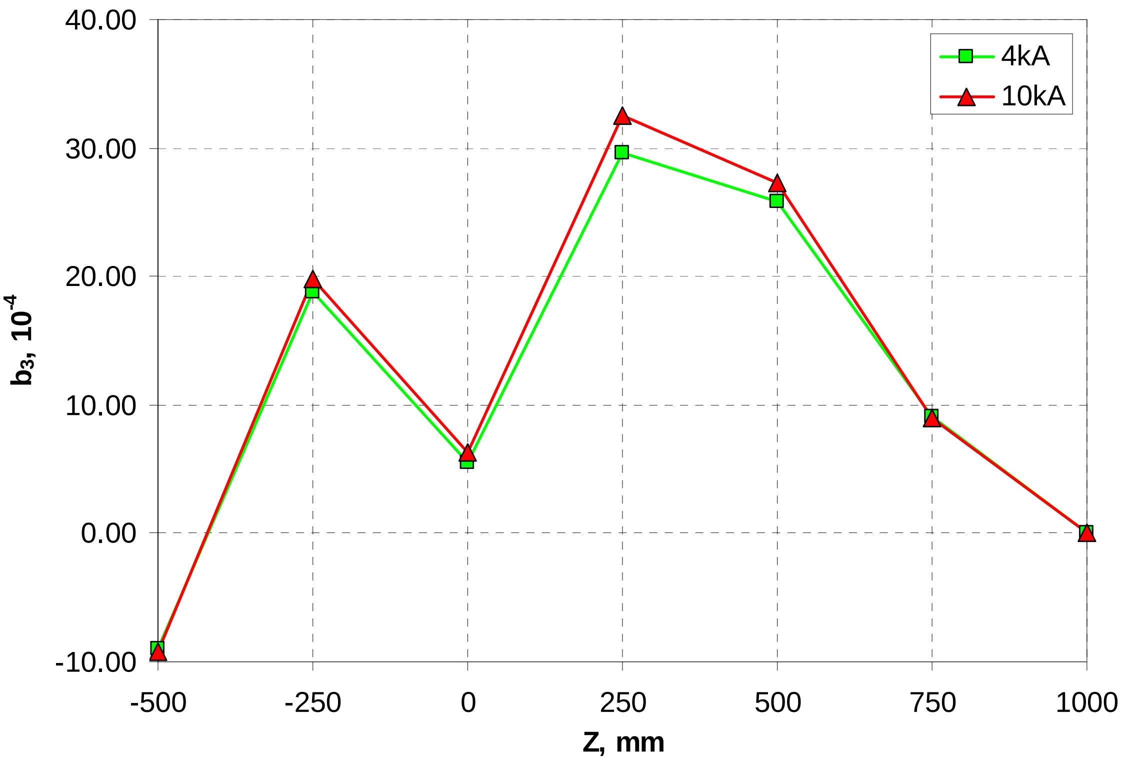

Figure 4. Normal sextupole along Z-axis.

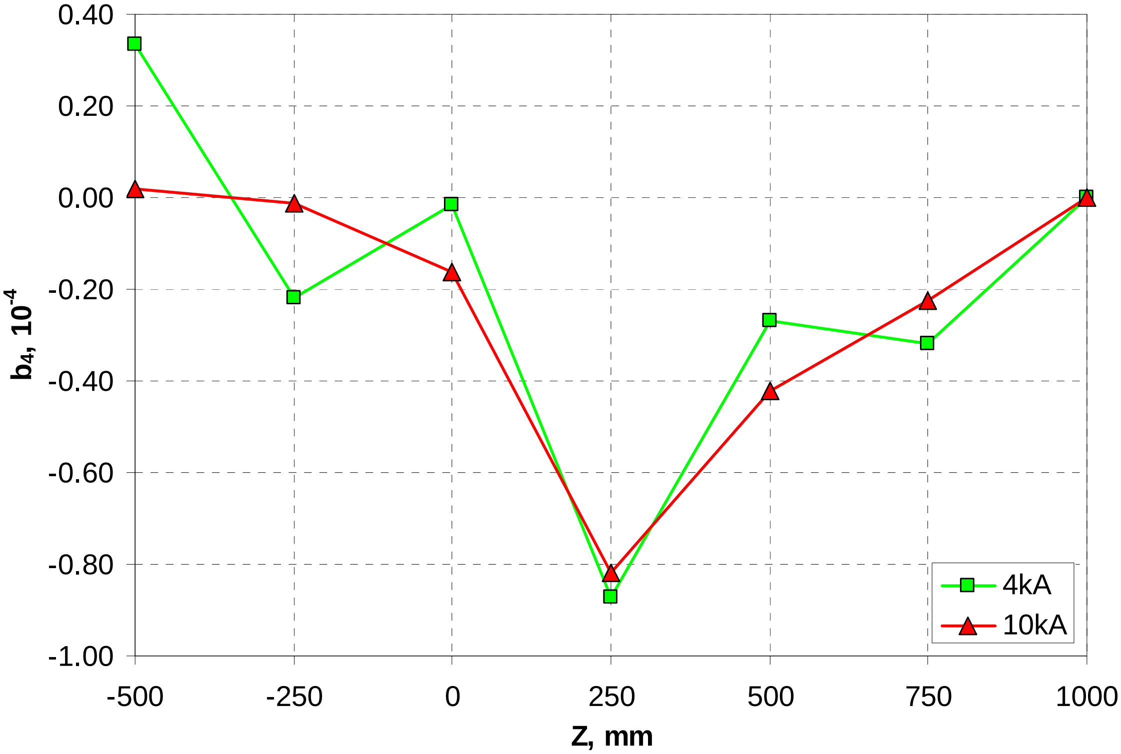

Figure 5. Normal octupole along Z-axis.

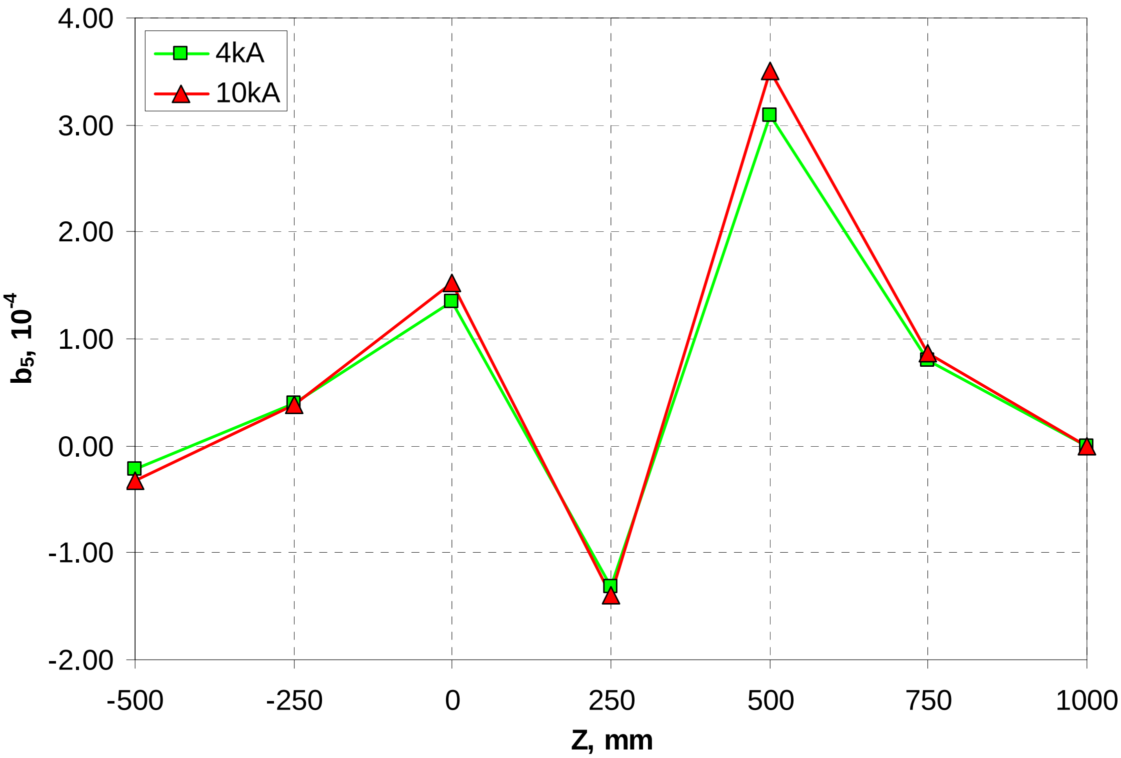

Figure 6. Normal decapole along Z-axis.

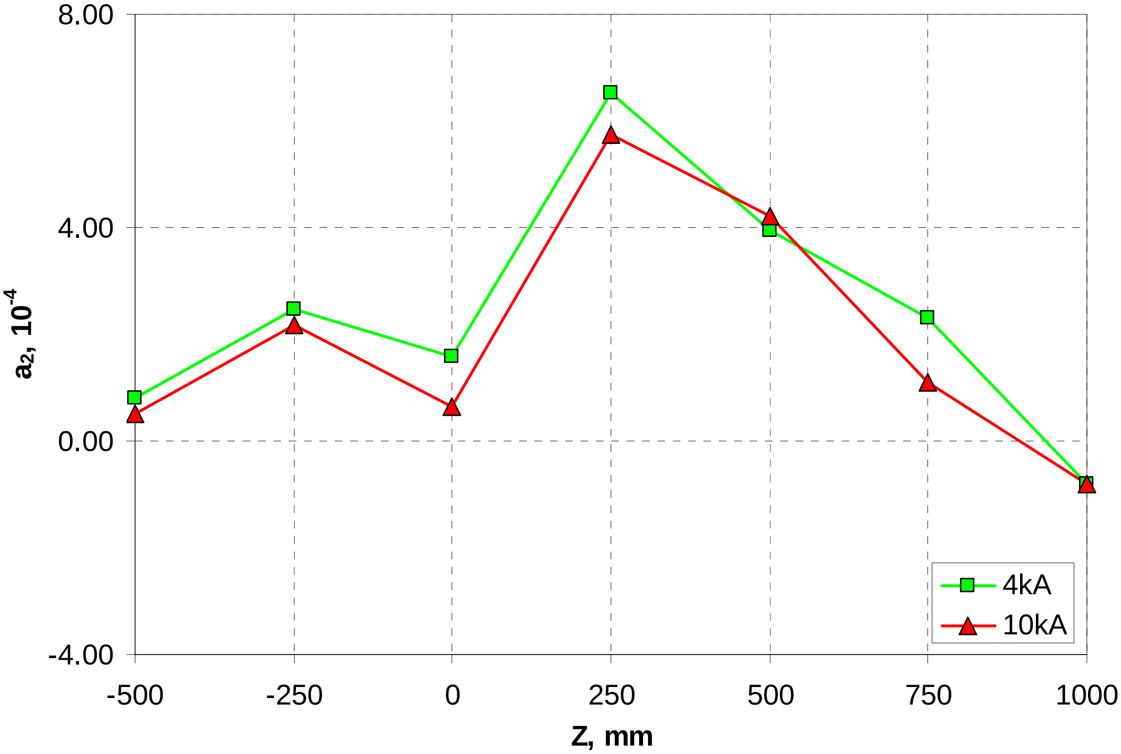

Figure 7. Skew quadrupole along Z-axis.

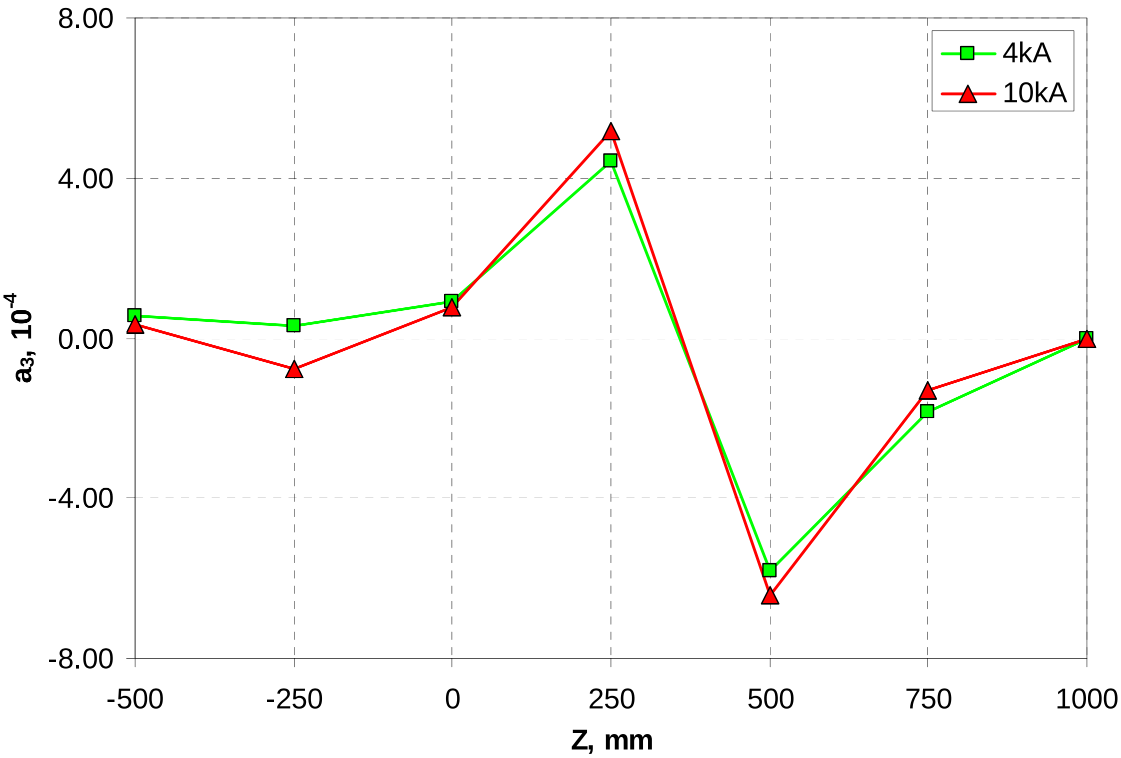

Figure 8. Skew sextupole along Z-axis.

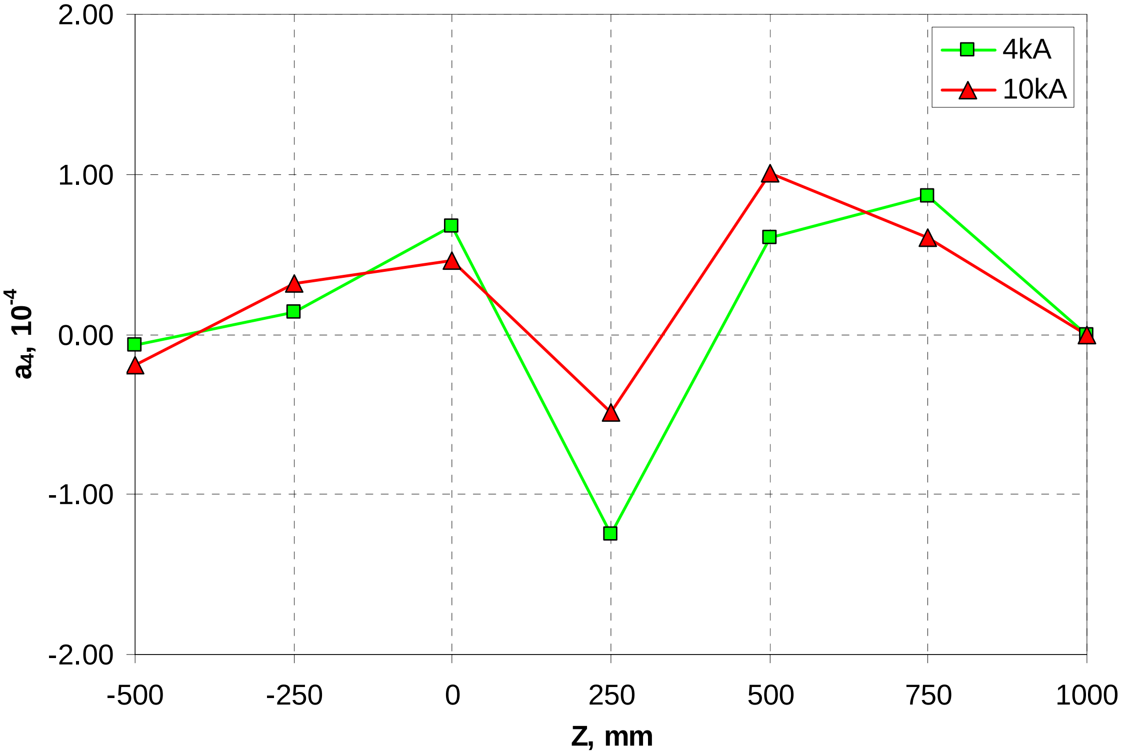

Figure 9. Skew octupole along Z-axis.

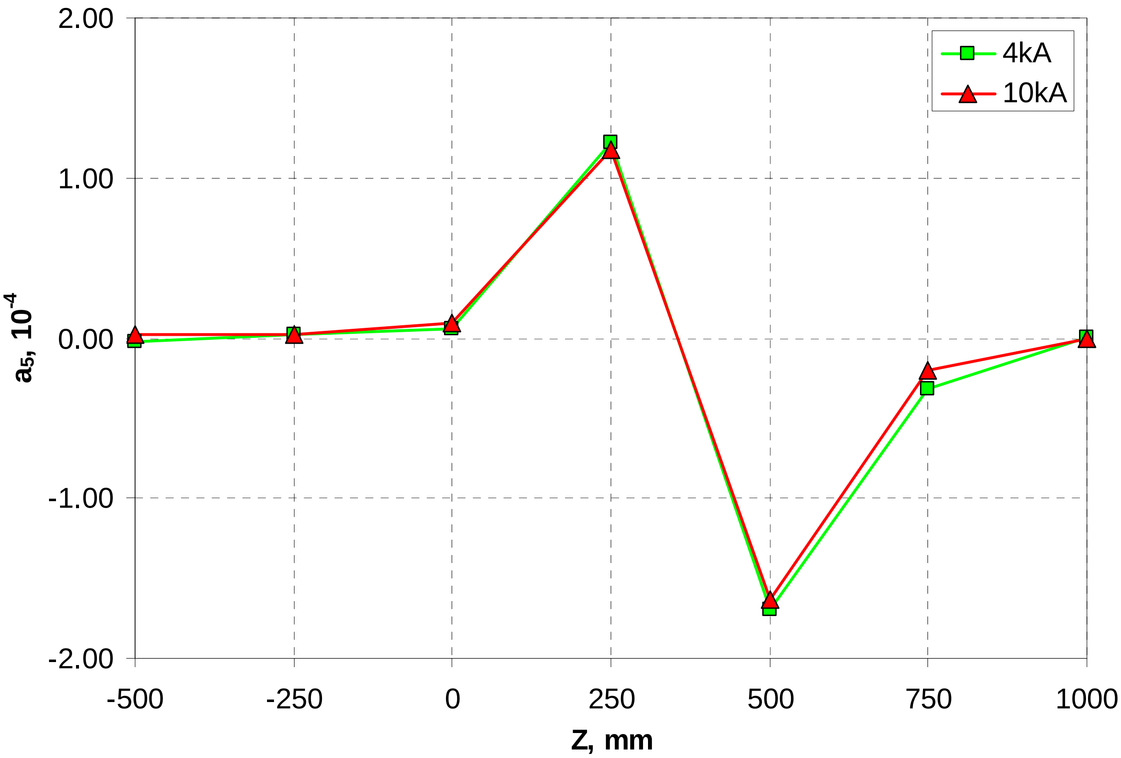

Figure 10. Skew decapole along Z-axis.

Hysteresys loops

The loop measurements were performed in two consecutive cycles up to 16000 A with the ramp rate 20 A/s; up to 15000 A with the ramp rate 40A/s; and up to 13000 A with the ramp rate 80 A/s. There was observed an abnormal inversed behavior in harmonics (similar to HFDA05-06), possibly attributed to large interstrand coupling currents in the cable. Figures 11-14 present the normal and skew quadrupole and sextupole components in the second cycles as functions of the main field component. A stair-step measurement was performed in order to acquire more data on this effect.

Stair-step measurement

The current was gradually ramped up to 16000 A with 2000 A steps and then ramped down in the similar way. The ramp rate was 20 A/s and the dwell time at each step was 60 seconds. Figure 15 shows the sextupole harmonic as a function of field and Figure 16 shows sextupole harmonic and current as functions of time. From Figure 17 presenting a typical stair-step one can see that the ramp-induced sextupole relaxation time is ~40 s (similar to HFDA05-06).

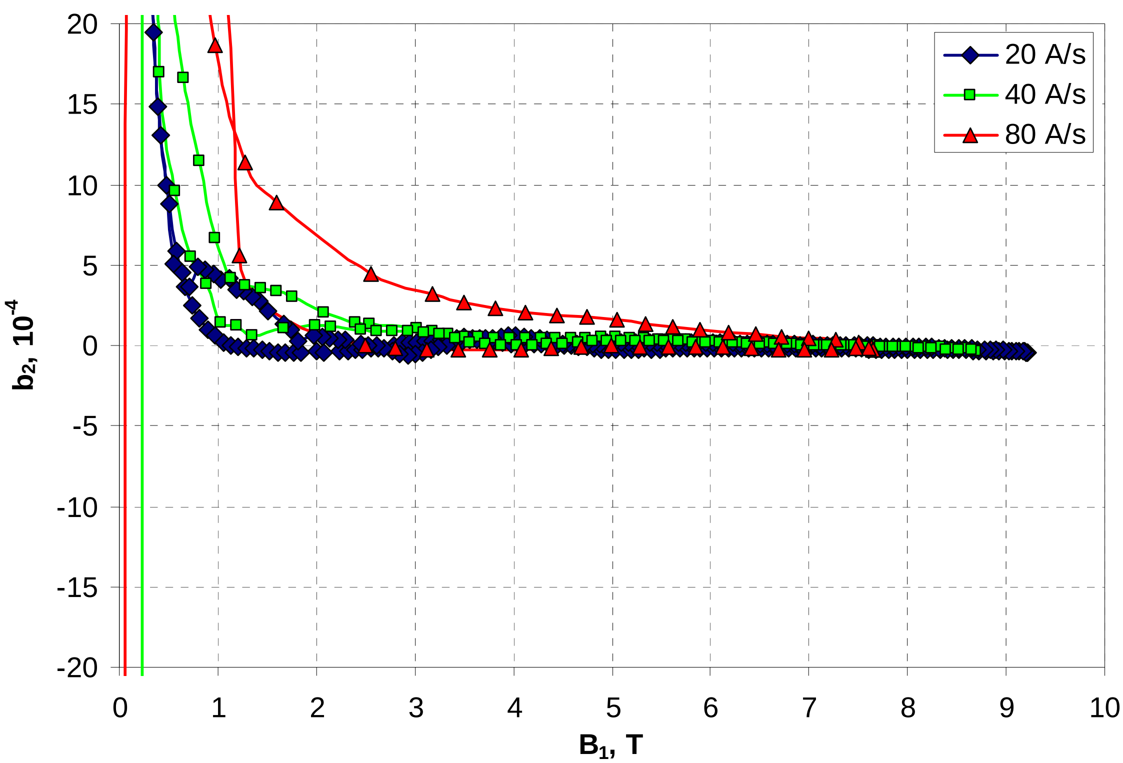

Figure 11. Normal quadrupole loops.

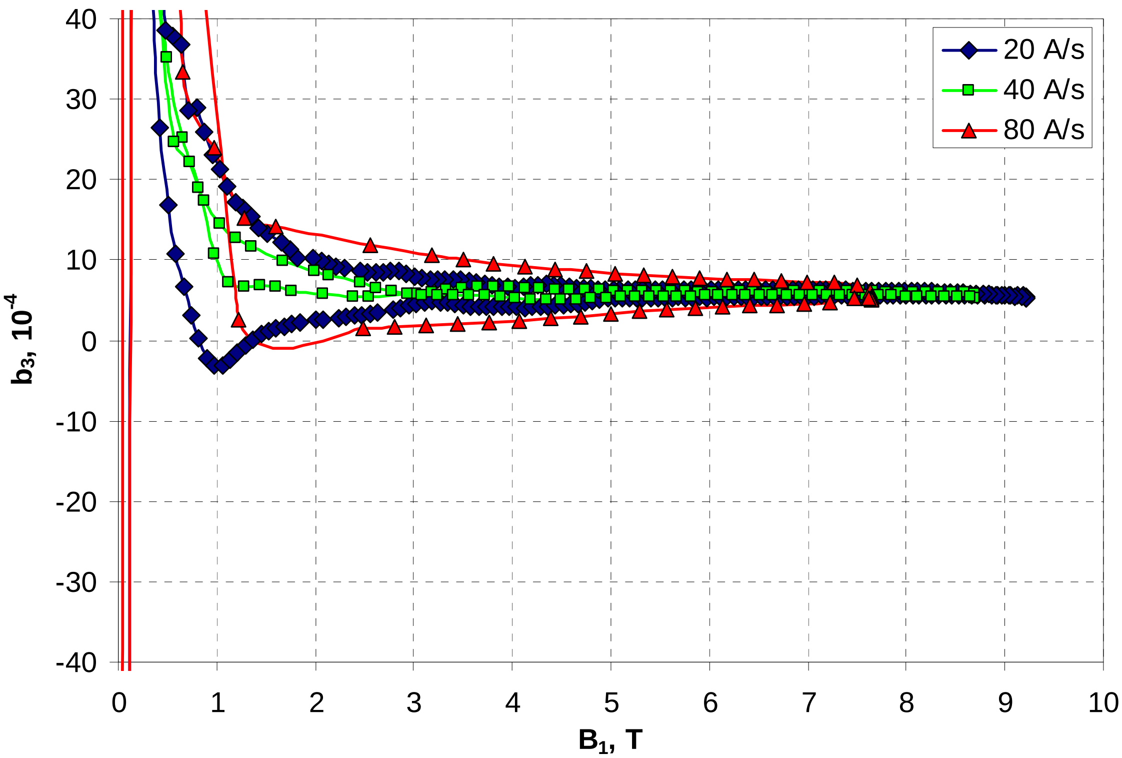

Figure 12. Normal sextupole loops.

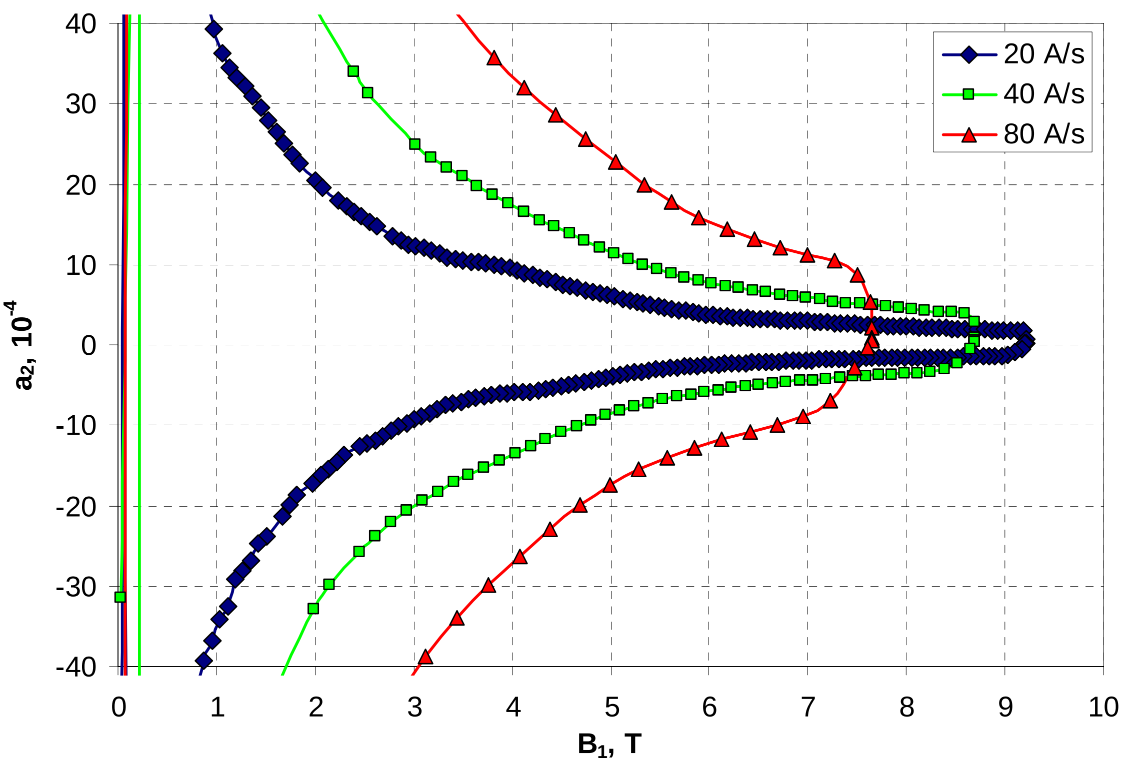

Figure 13. Skew quadrupole loops.

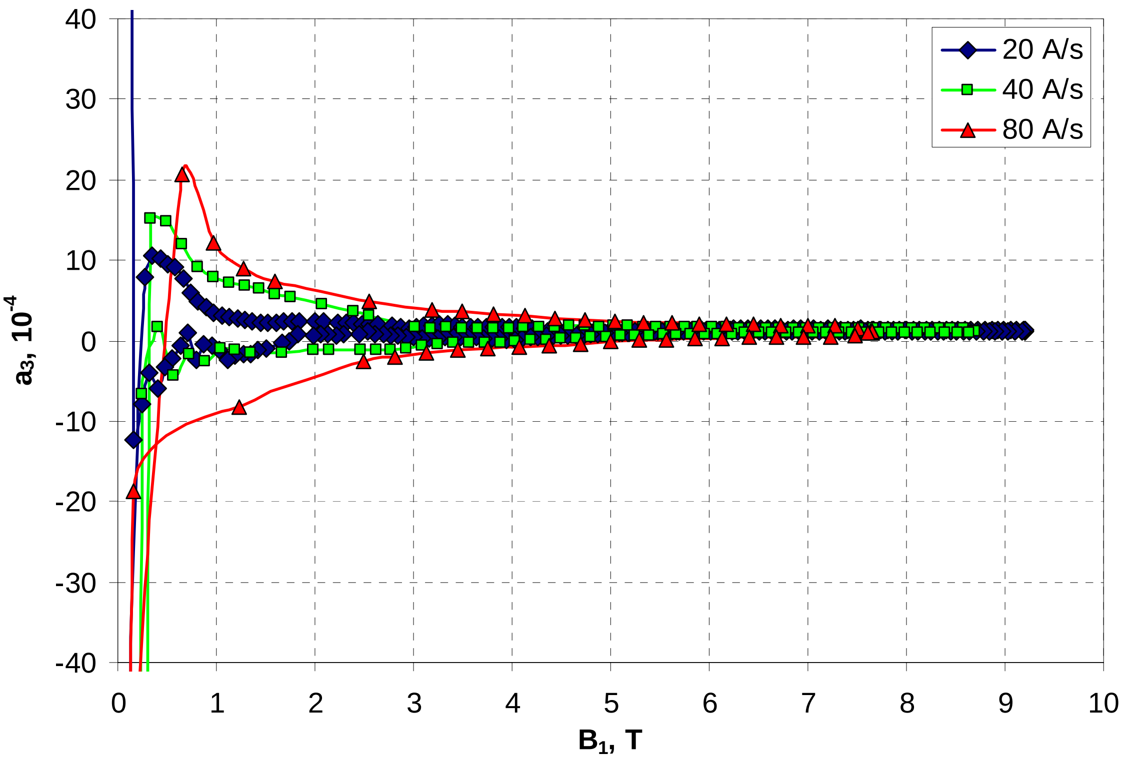

Figure 14. Skew sextupole loops.

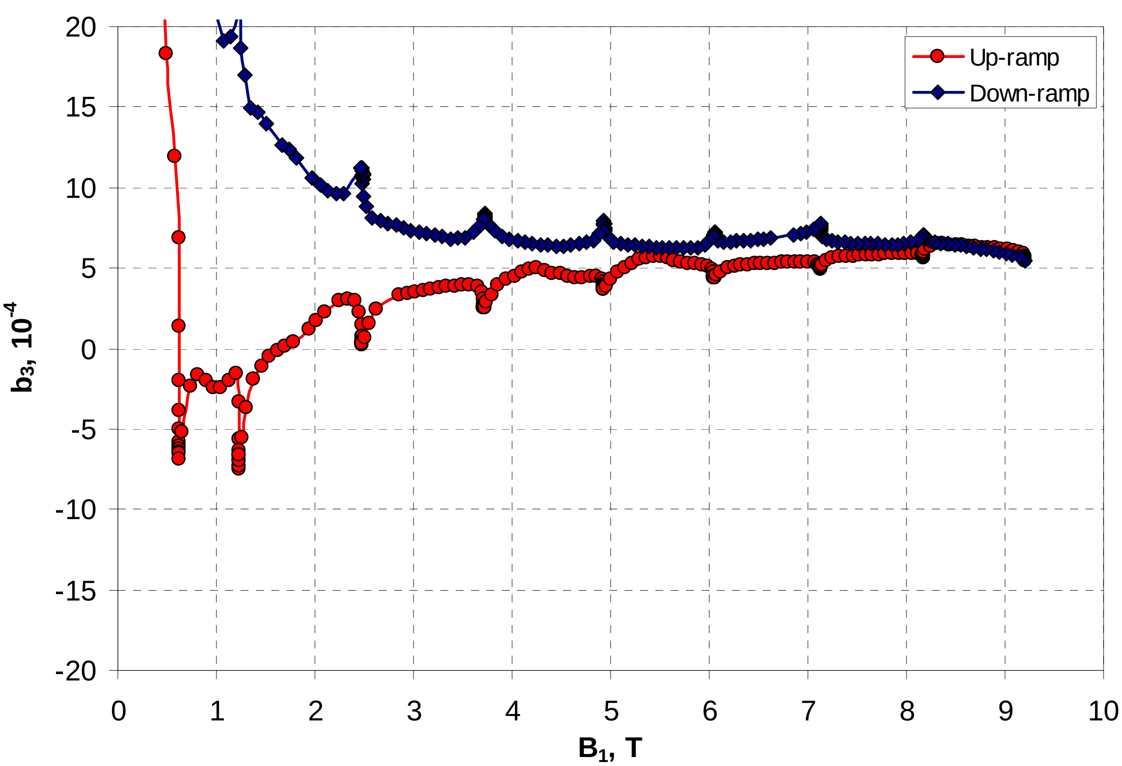

Figure 15. Sextupole as a function of field.

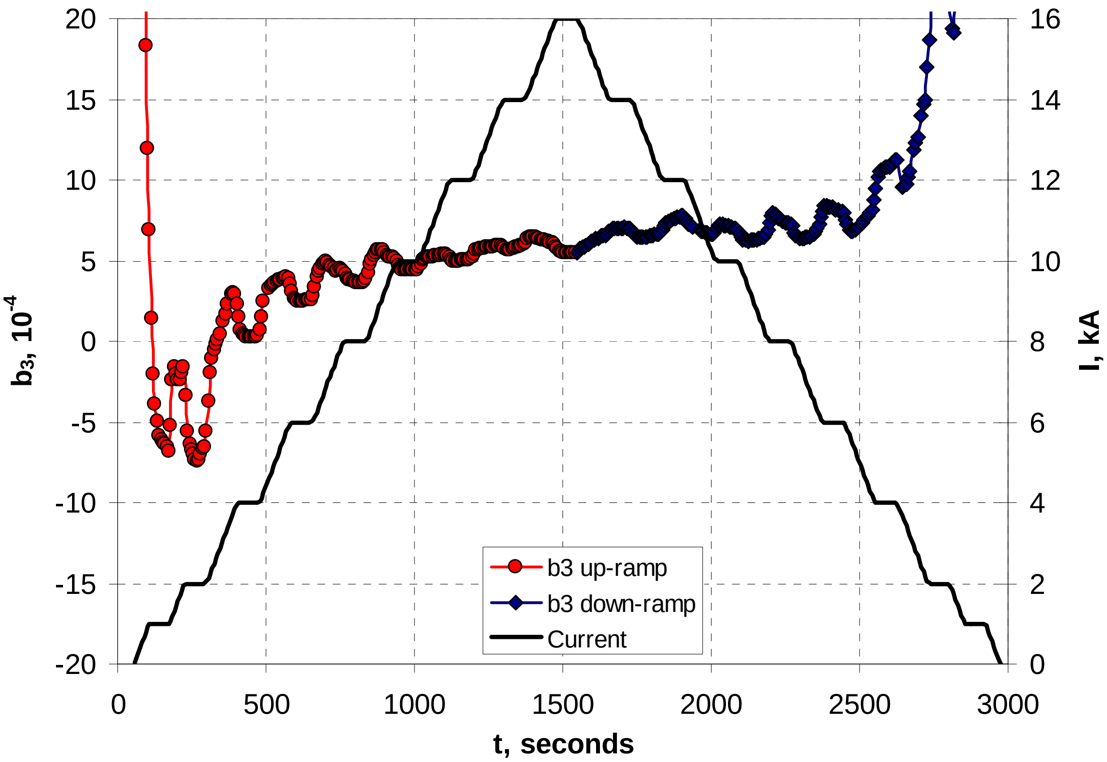

Figure 16. Sextupole and current as functions of time.

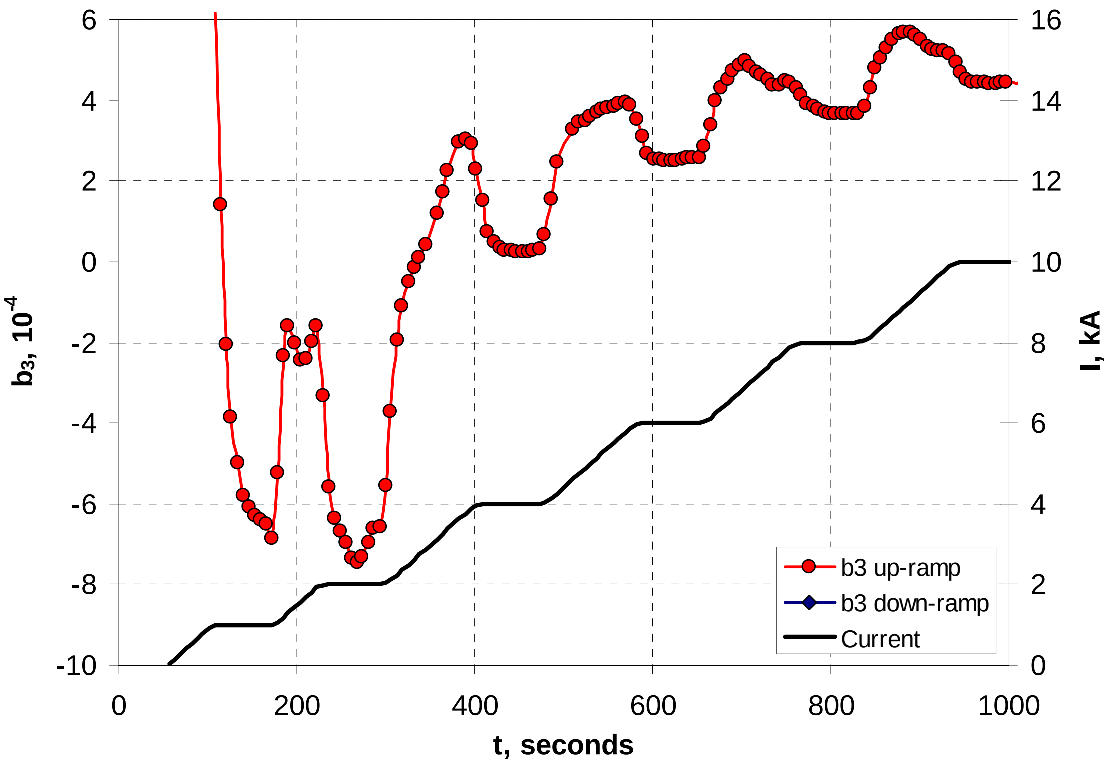

Figure 17. Sextupole and current as functions of time.

Accelerator profile (snap-back) measurements

Long-term harmonic decay and snap-back were measured during 30 minutes at 4400 A plateau following the pre-cycle up to 16000 A. Figure 18 shows the sextupole and current profiles during the whole measurement and Figures 19-20 present the normal and skew sextupoles and quadrupoles and current at the 30 minutes plateau. The harmonics behavior was completely different from HFDA05 magnet, but similar to HFDA06 magnet. There was no large long-term decay. Instead, the average harmonic values changed by <0.5 units during the 30 minutes. However, there were non-periodic oscillations with ~0.5 unit amplitude around the average value during the first 10 minutes at the plateau that then changed into a slowly changing periodic pattern for the rest of the plateau.

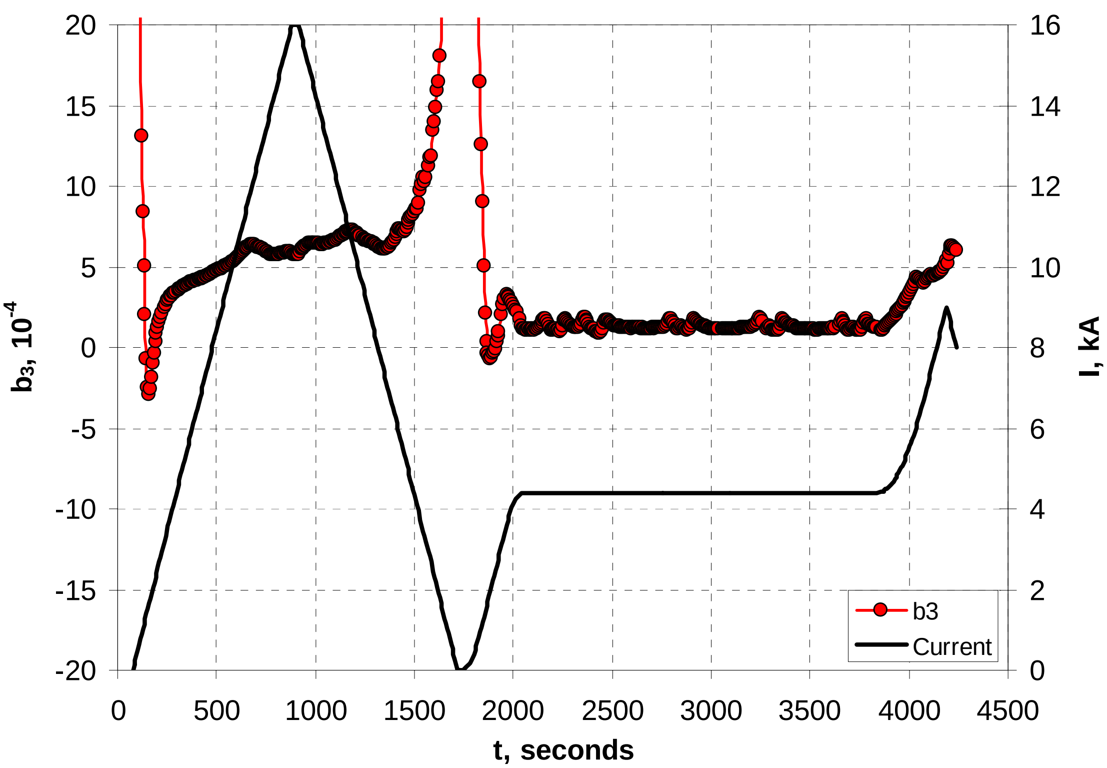

Figure 18. Sextupole and current as functions of time.

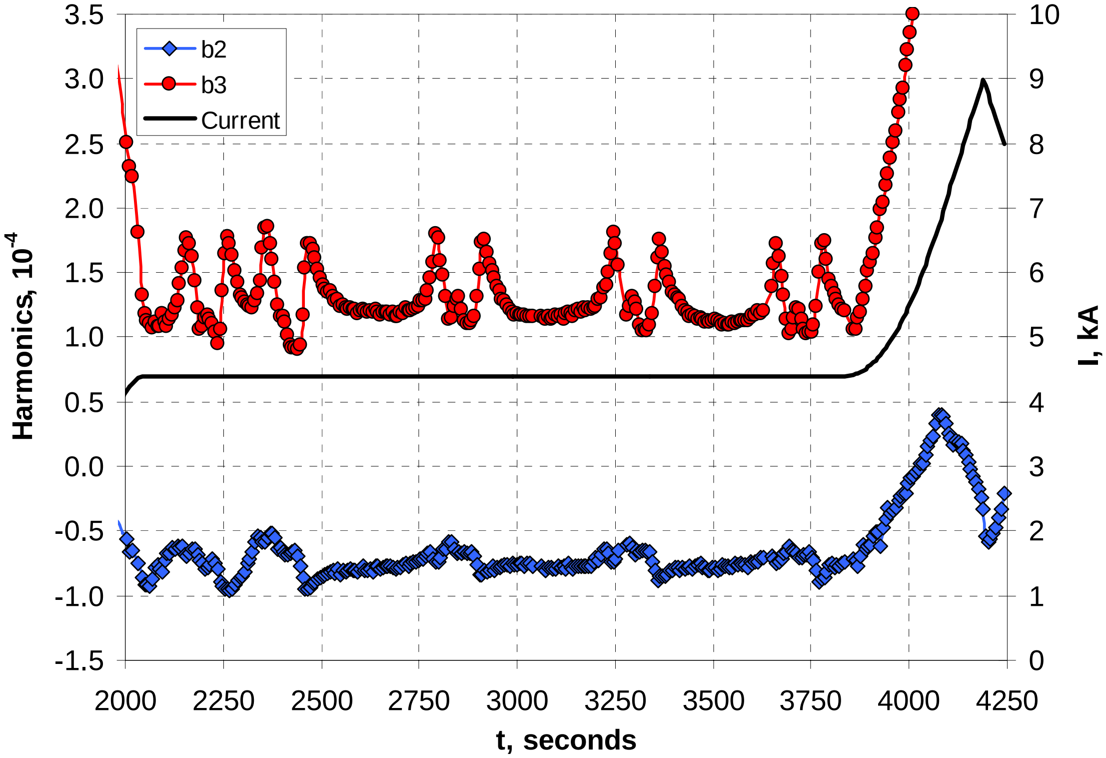

Figure 19. Sextupole, quadrupole and current as functions of time.

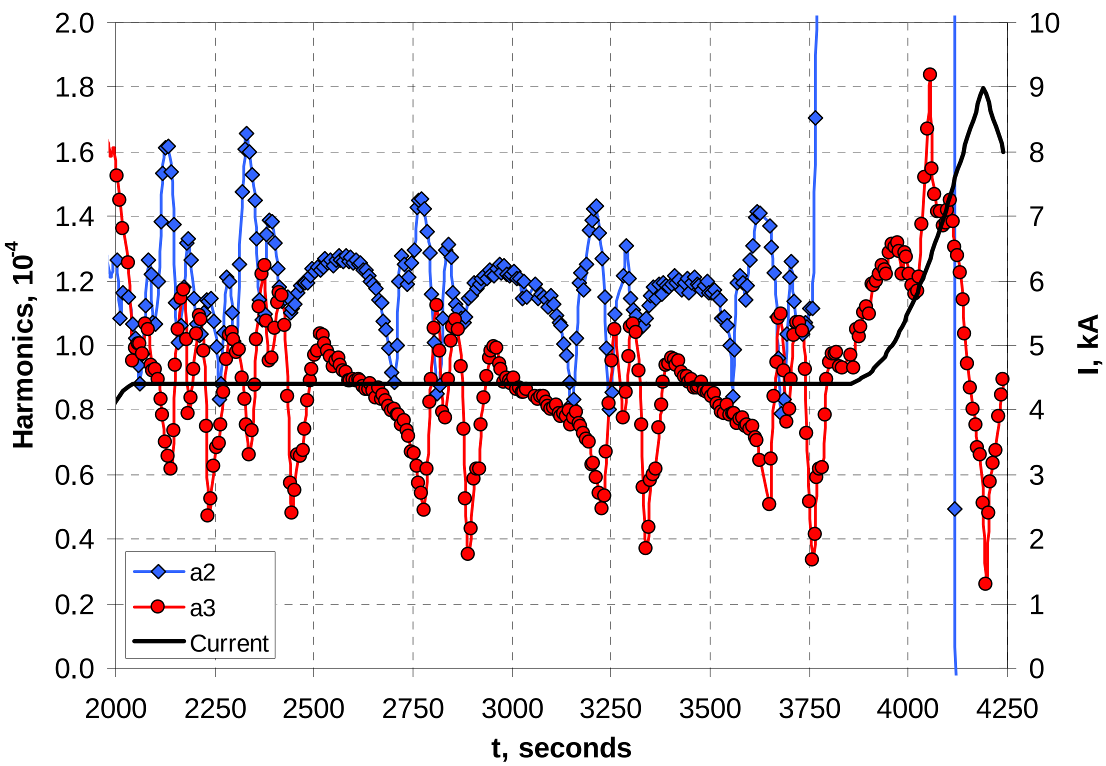

Figure 20. Skew sextupole, skew quadrupole and current as functions of time.